Communicating Personal Gadgets

Hans Scholten, Pierre Jansen, Laurens Hop

University of Twente, Department of Computer Science (EEMCS), Enschede, the Netherlands
Email: {scholten, jansen, hop}@cs.utwente.nl

Abstract— **This paper focuses on communication in personal area networks. A personal area networks (PAN) is characterized as an informal collection, or community, of connected small, lightweight, and resource-lean devices, or gadgets. Two basic concepts are visible in the development of PANs, the distributed and the centralized concept. The paper briefly introduces a real-time streaming media protocol that is suitable for both concepts. The protocol can deal with several types of traffic: real-time or non-real-time, bursty or isochronous, high or low bitrate. The protocol is undemanding in terms of resources, so even simple devices can participate in the network. The network is simulated and a prototype is realized.**

Index Terms— **Personal area network, streaming media, wireless network, medium access protocol, community**

I. Personal Area Networks

Personal area networks (PANs) can be defined as a collection of portable devices that temporarily meet to accomplish a common task for their owners. This collective can take many forms, depending on context and setting, private or public: people and devices exchanging information among themselves or with their surroundings. In this context two diverging trends, which have implications for the communication structure, are visible.

Multi-Function Devices: this trend is characterized by "heavy" devices that integrate a multitude of functions, e.g. a mobile phone, which doubles as a notebook, calendar, calculator, game machine and mp3 player. Probably the user of such a device possesses other devices as well, such as a digital camera, or a PDA. Even if these devices can communicate together, there is still little or no integration or interoperability. When the camera is out of memory, it is not possible to make additional photos, even if the mp3 player has memory left. This example also shows that there is overlap in functions. All devices have memory of their own, which can not be shared. There is other overlap as well, like the PDA-like function in the mobile phone and the PDA. An advantage of all-in-one devices is that they can work stand-alone without being dependent on other devices.

Single-Function Devices: the new trend is single-function "light-weight" devices that can communicate together and complement each other. The system consists of one base station with basic functionality, complemented by small devices. The base station is called the "personal mobile gateway" or PMG. An analogy might be the image of a central computer surrounded by its peripherals. The PMG provides processing power, storage and a gateway to the outside world for the rest of the PAN. In the view of IXI [1] internal communication is by means of Bluetooth [2]. Communication with the outside world is through a cellular network modem. The only device able to function stand alone is the PMG. All other devices need at least the PMG to function properly. E.g. the digital camera can take a picture, but has no memory to store it. The PMG can be a dedicated device on its own, but it can also be integrated in one of the peripherals. The mobile phone is a probable candidate to function as PMG, because it is a device most people always carry. More than in a network of heavy devices, a PMG based system depends heavily on the network, because all information must be offloaded to the PMG or vice versa.

This work is sponsored by the Netherlands Organization for Scientific Research (NWO) under grant number 612.060.111, and by the IBM Equinox programme.

II. Communication Models

The two concepts for personal area networks described in the previous section have to be mapped on a network model. Three basic communication models are important in this context.

Ad Hoc Communication Fully Connected: this communication model knows no centralized authority and assumes that every node is able to communicate directly with every other node in the network. Every communication is only one hop long and a broadcast will be received by all nodes.

Ad Hoc Communication with Hidden Nodes: as in the previous model this model has no centralized authority. However, in this model hidden nodes may be present. A hidden node is a node that is only visible by a subset of the nodes in a community. This is illustrated in figure 1. In this case node STA 5 is a hidden node and is only visible to node STA 2. STA 5 has always to communicate via STA 2. Thus STA 5 is one hop away from STA 2, but from STA 1, 3 and 4 it is two hops away. Assuming that a simple transfer of data in the fully connected model has a delay of τ, whenever STA 2 is relaying, a transfer has a delay of $2\cdot\tau$.

Managed Communication: the managed network is, like the first model, a fully connected network. In this case this is achieved by communication via a centralized authority that is

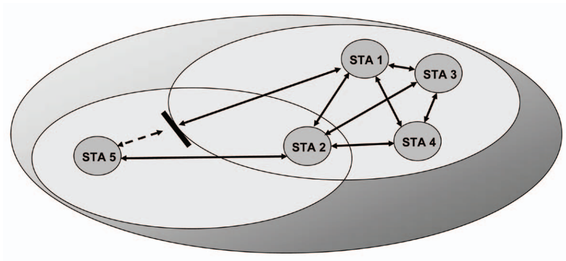

Fig. 1. Ad hoc network with hidden nodes

visible to all nodes. Communication between two nodes has always a delay of $2 \cdot \tau$.

A. Mapping Multi-Function Devices

Although the managed network model can be used, the most natural model for a personal area network consisting of "heavy" multi-function gadgets is the ad hoc network model. The gadgets have all the resources on board to function stand alone and they do not rely on other devices, e.g. the digital camera does not need other devices to take and store a picture.

The network function is in most cases used to upload or download content and not for distributed or collaborative work. The mobile phone and the notebook are in this view the most central devices. The mobile phone is used to connect other devices with the outside world via GPRS or UMTS, while the notebook is used to connect to a backbone network or to store content. But despite these functions, the phone and notebook are mere peers in the system. Even though they have a central function, like the traditional gateway, they do not coordinate the PAN.

B. Mapping Single-Function Devices

Because a collection of single-function devices in combination with a personal mobile gateway has a logical natural order, the managed network model seems appropriate. The PMG is the centre of things and the gadgets rely on it to function properly. This model has the disadvantage that communication needs two hops and delays between two gadgets is $2 \cdot \tau$. In spite of this disadvantage it is a suitable model.

An alternative is the ad hoc fully connected model. The PMG is always reachable in one hop by any gadget and gadgets can communicate mutually in one hop without de need for the PMG to relay messages. Communication delays are always one τ in this model.

The ad hoc model with hidden nodes is less suitable. Because a communication can be multi-hop, delays can become unacceptable long. Messages need to be relayed by the gadgets and have to be stored in the relaying gadgets. With high bandwidth streams the need for buffer capacity can be demanding. In addition routes through the network must be calculated and routing tables have to be kept. Instead of "lean" devices this requires full-fledged ones, which contradicts the concept of single-function devices.

Figure 2 summarizes the best mappings of devices on network models.

Type	AH FC	AH HN	Managed
MF	•	•	–
SF	•	–	•

AH FC: Ad Hoc Fully Connected
AH HN: Ad Hoc Hidden Nodes
MF: Multi-Function Device
SF: Single-Function Device

Fig. 2. Summary network mapping

III. Real-Time Communication

In the previous sections we mentioned that PANs must be able to cope with streaming data with high bandwidth needs and strict timing. We have given a mapping of device types on a network model. Now we briefly introduce a network protocol for PANs that supports these data types and that can be used in the network models.

A. Single-Hop Network Scheduling

Malcom and Zhao [3] and Sevcik and Johnson [4] describe real-time networks, like IEEE802.4 token bus, IEEE802.5 token ring and FDDI, that are based on passing around tokens. The token visits the nodes in the network according to a simple scheme, such as round robin. When a node receives the token it is allowed to use the network during a predefined time, the token holding time or THT. This THT may be different for different nodes. Even if a node has nothing to send it will get the token during a round, which may lead to considerable loss of bandwidth.

We have proposed a more advanced way to direct the token in the network [5] [6]. The token is scheduled based on preemptive earliest deadline first (PEDF) scheduling. A stream is pre-empted in favour of a new stream if the latter has an earlier deadline. When the new stream ends, the previous stream is restored. The scheduler that calculates the schedule can be distributed or reside in a single node. The current prototype [7] uses a distributed scheduler. Schedule information is passed on via the token. The centralized scheduler can be used in the managed network model, where the PMG can calculate and give out the token to the gadgets. Any stream that is accepted in the network must keep its deadlines. The PEDF scheduler can guarantee this if the total of streams does not exceed the network's capacity. Before a new stream is admitted to the network, the system must check whether the new set of streams is feasible. Under the assumption that a stream's period is equal to its deadline, a set of periodic streams is schedulable with PEDF if and only if

$$\sum_{i=1}^{n} \frac{B_i}{B} \leq 1$$

Where n: Number of streams; B_i: Bandwidth of stream i; B: Maximum bandwidth of the network.
When the streams in the network meet this requirement, the PEDF scheduler will find a schedule. PEDF has the nice property that it gives 100 percent utilization of the network bandwidth.

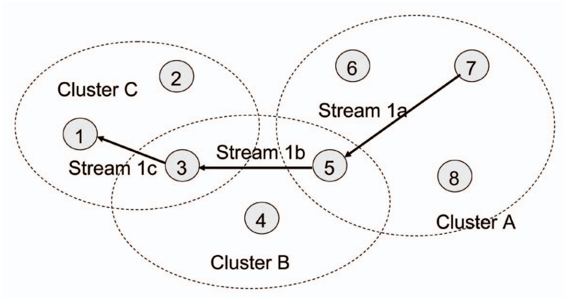

Fig. 3. Example of a multi-hop network

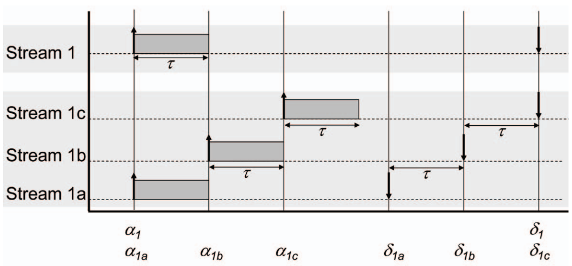

Fig. 4. Multi-hop PEDF schedule

B. Multi-Hop Network Scheduling

The principle of single-hop network scheduling is extendible to multi-hop networks. In the example of figure 3 a (periodic) stream from node 7 to node 1 is relayed by two intermediate nodes – 5 and 3 – in the network. The network is divided in three clusters, where every cluster is a fully connected (sub)network. Some nodes are in more than one cluster, which makes them potential relays for transmissions from one cluster to an other.

In the example (figure 3) a stream is divided in three sub-streams, and each frame of the stream will be transmitted one after the other. This is shown in figure 4, where one period of the stream is shown with an arrival time α_1 and a deadline δ_1. Sub-stream 1_a has the same arrival time α_{1a} as stream 1, and sub-stream 1_c has the same deadline δ_{1c} as stream 1. Because stream 1_b has to be received by node 3 before stream 1_c can be sent by the same node, the deadline δ_{1b} of stream 1_b equals the latest possible arrival time α_{1c} of stream 1_c:

$$\begin{array}{ll} \alpha_1; \delta_1 & (stream1) \\ \alpha_{1a} \geq \alpha_1; \delta_{1a} \leq \delta_{1b} - \tau & (stream1_a) \\ \alpha_{1b} \geq \alpha_{1a} + \tau; \delta_{1b} \leq \delta_{1c} - \tau & (stream1_b) \\ \alpha_{1c} \geq \alpha_{1b} + \tau; \delta_{1c} \leq \delta_1 & (stream1_c) \end{array}$$

Figure 4 shows a possible scheduling of the sub-streams. The scheduler has to ensure that stream 1_a is transmitted before stream 1_b, and stream 1_b before stream 1_c. This is guaranteed by the PEDF scheduler when:

$$\begin{array}{l} \alpha_{1a} \leq \alpha_{1b} \leq \alpha_{1c} \\ \delta_{1a} < \delta_{1b} < \delta_{1c} \end{array}$$

The limits for α's and δ's for the sub-streams meet these requirements. Because the network has to accommodate three sub-streams instead of one stream, the total requested bandwidth is three times the original bandwidth. In general, a set of streams, where each stream i is composed of s_i sub-streams, is feasible if and only if

$$\sum_{i=1}^{n} \frac{s_i \cdot B_i}{B} \leq 1$$

Where n: number of streams; s_i: number of sub-streams in stream i; B_i: bandwidth of original stream i; B: Maximum bandwidth of the network.

This token scheme is applicable to both ad hoc and managed network models. For the managed network model the number of hops, and the number of sub-streams, is always two. For the ad hoc fully connected network model the number of hops is always one. And for the ad hoc with hidden nodes network model the number of hops is variable.

IV. Conclusion

In this paper we identified two trends according to the type of devices – and philosophy – the PAN is based on: the multi-function and the single function devices. Three suitable network communication models are introduced and a mapping of both trends on these models is given.

We introduced a real-time token protocol that is able to support streaming data in the three different communication models. The protocol is based on a distributed pre-emptive earliest deadline first scheduler. PEDF guarantees an efficient use of bandwidth, up to one hundred percent. Still the check for available bandwidth, the feasibility analysis, is simple enough to be implemented in small devices. The communication models involve single and multi hop communications. We showed how a multi hop stream can be split up in a consecutive sequence of sub-streams, and under which conditions the pre-emptive earliest deadline first scheduling guarantees the necessary order of streams in the network. The resulting set of streams can be considered as a "normal" set of single hop streams and the PEDF schedule can be calculated.

References

[1] IXI, "The ixi web site," Website: 'http://www.ixi.com'.
[2] Bluetooth, "The bluetooth special interest group web site," Website: 'http://www.bluetooth.org'.
[3] N. Malcom and W. Zhao, "The timed token protocol for real-time communications," *IEEE Computers*, vol. 10, no. 1, p. 3541, Jan. 1994.
[4] K. Sevcik and M. Johnson, "Cycle time properties of the fddi token ring protocol," *IEEE Transactions on Software Engineering*, vol. 13, no. 3, pp. 376–385, Mar. 1987.
[5] J. Scholten, P. G. Jansen, F. T. Y. Hanssen, P. H. Hartel, T. Hattink, and V. Sundramoorthy, "Multimedia QoS in low-cost home networks," in *27th Annual IEEE Conference on Local Computer Networks (LCN).* Tampa, Florida: IEEE Computer Society Press, Los Alamitos, California, Nov 2002, pp. 327–328.
[6] F. T. Y. Hanssen, P. H. Hartel, T. Hattink, P. G. Jansen, J. Scholten, and J. Wijnberg, "A Real-Time ethernet network at home," in *Research report 36/2002*, M. G. Harbour, Ed. Vienna, Austria: Real-Time Systems Group, Vienna Univ. of Technology, Jun 2002, pp. 5–8.
[7] W. H. Mank and A. Zwikker, "Designing and prototyping the real-time rtnet protocol on wireless lan," Master's thesis, University of Twente, November 2002.